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TECHNICAL NOTES

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

No. 630

FREE-SPINNING WIND-TUNNEL TESTS OF A LOW-WING MONOPLANE WITH SYSTEMATIC CHANGES IN WINGS AND TAILS

II. MASS DISTRIBUTED ALONG THE FUSELAGE

By Oscar Seidman and A. I. Neihouse
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SUMMARY

Eight wings and three tails, covering a wide range of aerodynamic characteristics, were independently ballasted so as to be interchangeable with no change in mass distribution. For each of the 24 resulting wing-tail combinations, observations were made of the steady spin for four control settings and of recoveries for five control manipulations, the results being presented in the form of charts comparing the spin characteristics. The tests are part of a general investigation that is being made in the N.A.C.A. free-spinning tunnel to determine the effects of systematic changes in wing and tail arrangement upon the steady spinning and the recovery characteristics of a conventional low-wing monoplane for various loading conditions.

One series of tests, that for the basic loading condition, has been reported in N.A.C.A. Technical Note No. 608. The present loading condition was derived from the basic loading condition by moving weight from the wing tips toward the center of gravity, leaving the model with its mass distributed chiefly along the fuselage.

For the tails having a deepened fuselage and a raised stabilizer, recovery was satisfactory and the results were very similar to those previously reported for the basic loading condition. For the more nearly conventional tail, the effects of wing plan form and tip shape were quite marked and there appeared to be an adverse effect of the present loading, except for the case of the wing of N.A.C.A. 6718 section, which gave more rapid recovery than for the basic loading condition.

INTRODUCTION

The N.A.C.A. has undertaken a systematic investigation in the free-spinning wind tunnel (reference 1) to determine, by major independent variations, which of the dimensional and mass characteristics of an airplane most greatly affect the spin.

The results of tests of eight wings and three tails for a basic loading condition, which is representative of an average of values for 21 American airplanes for which the moments of inertia were available, have been reported in reference 1. The present report contains the results of a similar series of tests for a loading obtained by moving weight from the wing tips toward the center of gravity, thereby leaving the model with its mass chiefly distributed along the fuselage. This loading condition closely agrees with a value obtained by averaging the available mass distribution parameters for nine modern low-wing monoplanes.

The major wing variables include tip shape, airfoil section, plan form, and flaps. The Army standard tapered wing, also included in the test program, combines changes in plan form and thickness. The three tail arrangements range from a combination utilizing full-length rudder and raised stabilizer on a deep fuselage, designed to be extremely efficient in providing yawing moment for recovery, to a more nearly conventional type with rudder completely above a shallow fuselage and badly shielded by the horizontal surfaces. The present results are compared with the results obtained for the basic loading condition.

APPARATUS AND METHODS

A general description of model construction and testing technique in the N.A.C.A. free-spinning tunnel is given in reference 2.

The models are constructed of balsa, reinforced with spruce and bamboo. In order to reduce the weight, the fuselage and wings are hollowed out, the external contours being maintained by means of silk tissue paper on reinforcing ribs. The desired loading is attained by suitable distribution of lead weights.

Figures 1 to 5 show special structural features of the model tested. The wing and tail units are independently removable and interchangeable to permit testing any combination. The exchange of units can be made without any change in mass distribution. A clockwork delay-action mechanism was installed to actuate the controls for recovery, simulating the rapid motions that would be imparted by a pilot.

The low-wing monoplane model was not scaled from any particular airplane but was designed to be a representative low-wing cabin monoplane with cowled radial engine and with landing gear retracted. Dimensional characteristics of the model and of the eight wings and three tails are given on the line drawings of figures 1, 2, and 3. The present model loading condition was derived from the basic condition (reference 1) by removing weights from the wing tips and installing them at the center of gravity. For convenience in making comparisons, the model may be considered a 1/15-scale model of either a fighter or a four-place cabin airplane, tested at an altitude of 6,000 feet. The full-scale characteristics for the present loading and tail C would be:

Weight (W).	4,720 lb.
Mean chord (c).	75 in.
Span (b).	37.5 ft.
Wing area (S)	234.4 sq. ft.
Aspect ratio	6
Distance from c.g. to elevator hinge.	16.6 ft.
Distance from c.g. to rudder hinge .	16.9 ft.
Fin area	6.8 sq. ft.
Rudder area	6.9 sq. ft.
Stabilizer area	19.8 sq. ft.
Elevator area	12.9 sq. ft.
Control travel	Rudder: $\pm 30^\circ$
	Elevator: 30° up 20° down

Principal moments of inertia:

$A = mk_X^2$ . . . . 2,310 slug-ft.^{2}

$B = mk_Y^2$ . . . . 3,970 slug-ft.^{2}

$C = mk_Z^2$ . . . . 5,700 slug-ft.^{2}

The dimensionless mass-distribution parameters for the present loading condition are:

$$\mu = \frac{W}{g\rho Sb} = 7$$

$$\frac{Wb^2}{g(C - A)} = 61$$

$$\frac{C - B}{C - A} = 0.51$$

$$\frac{b}{k_X} = 9.4$$

$$\frac{x}{c} = 0.25$$

$$\frac{z}{c} = 0$$

The quantity x/c is the ratio of the distance of the center of gravity back of the leading edge of the mean chord to the mean chord; and z/c is the ratio of the distance of the center of gravity below the thrust line to the mean chord.

Figures 1 and 4 show the model with the basic wing (wing 1) and tail C installed. This wing is of N.A.C.A. 23012 section with rectangular plan form and Army tips. (The tip contour is derived as described in reference 3.) In common with the other wings, it has an area of 150 square inches, a span of 30 inches, and no dihedral, twist, or sweepback.

The seven remaining wings (figs. 2 and 5) have varied dimensional characteristics as follows:

Wing 2: N.A.C.A. 23012 section, rectangular with Army tips, 20 percent split flaps deflected 60°.

Wing 3: N.A.C.A. 23012 section, rectangular with rectangular tips.

Wing 4: N.A.C.A. 23012 section, rectangular with faired tips.

Wing 5: N.A.C.A. 0009 section, rectangular with Army tips.

Wing 6: N.A.C.A. 6718 section, rectangular with Army tips.

Wing 7: N.A.C.A. 23012 section, 5:2 taper with Army tips.

Wing 8: N.A.C.A. 23018-09 section, Army standard plan form (square center section, 2:1 taper in both plan form and thickness, and Army tips).

The three tails designated A, B, and C (figs. 3 and 5), differ in vertical tail area, in fuselage side area, and in vertical location of the horizontal surfaces. Tail C, representing a conventional shallow fuselage with rudder completely above the tail cone, has the following dimensional characteristics:

Vertical tail area: 6 percent wing area (3 percent rudder and 3 percent fin).

Fuselage side area, back of leading edge of stabilizer: 2 percent wing area.

Vertical tail length (from quarter-chord point to rudder hinge axis): 45 percent wing span.

Horizontal tail area: 14 percent wing area (5.5 percent elevator and 8.5 percent stabilizer).

Horizontal tail length (from quarter-chord point to rudder hinge axis): 44 percent wing span.

Tail B was derived from tail C by increasing the

fuselage depth, raising the stabilizer and elevators, and installing approximately the original fin and rudder atop the deepened fuselage. For tail B the vertical areas are:

Vertical tail area: 6 percent wing area.

Fuselage side area: 5.5 percent wing area.

Tail A was similar to tail B except for full-length rudder construction and slightly increased elevator cut-out. For tail A the vertical areas are:

Vertical tail area: 8 percent wing area (5 percent rudder and 3 percent fin).

Fuselage side area: 3.4 percent wing area.

RESULTS AND PRECISION

For each wing and tail combination, spin tests were made for four control settings:

(a) rudder 30° with the spin and elevators neutral.

(b) rudder 30° with the spin and elevators 20° down.

(c) rudder 30° with the spin and elevators 30° up.

(d) rudder neutral and elevators neutral.

Recovery from (a) and (b) was attempted by reversal of the rudder, from (c) by complete reversal of both controls and also by neutralizing both controls, and from (d) by moving both controls to full against the spin. All tests were for right spins.

The angle of attack α, angle of sideslip β, (positive inward in a right spin), turns for recovery, spin coefficient $\Omega b/2V$, and rate of descent V, are plotted in 12 charts (figs. 6 to 17), grouped so as to permit ready comparison of the effects of tip shape, section, plan form, flaps, and the Army standard wing.

The data on these charts are believed to represent

the true model values within the following limits (see reference 2):

α	$\pm 3^{\circ}$
β	$\pm 1\text{-}1/2^{\circ}$
Turns for recovery	$\pm 1/4$ turn
$\frac{\Omega b}{2V}$	± 3 percent
V	± 2 percent

For certain spins where it is difficult to control the spin in the tunnel, owing to high air speed or wandering motion, the foregoing limits may be exceeded.

DISCUSSION

Tests with tail A (figs. 6 to 9).- In figure 6 results are shown for different wings with tail A for rudder 30° with the spin and elevators neutral. It may be seen that rectangular wings with rectangular or faired tips (wings 3 and 4) gave the steepest spins ($\alpha = 49^{\circ}$ compared with 58° for the flattest) and the most rapid recoveries (1-1/2 turns); whereas, the wing with 5:2 taper (wing 7) and the wing with flaps deflected (wing 2) gave the slowest recoveries. The wing of N.A.C.A. 6718 section gave the least outward sideslip.

With elevators 20° down (fig. 7) the spins were very similar to those for elevators neutral. Elevators up (fig. 8) definitely steepened the spins and gave rapid recoveries by reversal of both controls. With controls neutral (fig. 9) a spin could be obtained only with the 5:2 taper wing, the model recovering of its own accord when forced into a spin for all other cases.

For all the control settings, the rectangular wings with rectangular or faired tips gave the steepest spins and the most rapid recoveries. The wing of N.A.C.A. 6718 section gave the least outward sideslip, a lower angle of attack, and a slightly faster recovery than the corresponding wings of N.A.C.A. 23012 and of N.A.C.A. 0009 sections. Recovery for the wing with flaps and the wing of

5:2 taper was slower than for the remaining wings, including the Army standard wing.

For tail A, there was very little difference in the results for this loading as compared with those for the basic loading (reference 1).

Tests with tail B (figs. 10 to 13).- Figure 10, which gives results for various wings with tail B for rudder with the spin and elevators neutral, shows general agreement with the results for tail A (fig. 6) except that the spins were of the order of 10° steeper. This result is not unexpected as the control arrangement might be interpreted as resulting from neutralizing the lower half of the full-length rudder of tail A.

As with tail A, the rectangular wings with rectangular or faired tips gave the steepest spins and the wing of 5:2 taper and the wing with flaps gave the slowest recoveries. The wing of N.A.C.A. 6718 section gave inward sideslip. With elevators 20° down (fig. 11) there was little difference in the spin. With elevators up (fig. 12) the spin was steepened and became too fast and wandering to be maintained in the tunnel.

With both controls neutral (fig. 13), tail B is almost identical in configuration and dimensions with tail A except for the slightly larger elevator cut-out of tail A. A spin was obtained not only for the wing of 5:2 taper but for the Army standard wing and, with difficulty, for the basic wing (wing 1) as well. The apparent inconsistency with the results for tail A may be due to the relatively smaller rudder-shielding effect with the larger elevator cut-out of tail A.

For all control settings, the rectangular wing with rectangular or faired tips gave the steepest spins and the best recoveries and the wing of N.A.C.A. 6718 section gave inward sideslip. For controls with the spin there was little other effect of section, and the flaps retarded recovery. The wing of 5:2 taper gave the poorest recovery but the Army standard tapered wing was satisfactory.

The results for tail B are generally similar to those for tail A. The wing of N.A.C.A. 6718 section gave greater inward sideslip with this loading than with the basic loading and the wing of 5:2 taper gave slower recoveries.

Tests with tail C (figs. 14 to 17).- With tail C the effects of individual wing differences were more apparent. Figure 14 shows that, for rudder with the spin and elevators neutral, the rectangular wing with rectangular or faired tips again gave the steepest spins ($\alpha = 40^\circ$) and most rapid recoveries. By comparison, the wing with Army tips was considerably poorer, giving no recovery. The wing of N.A.C.A. 6718 section gave inward sideslip and a considerably lower angle of attack and faster recovery than the corresponding wings of N.A.C.A. 0009 and of N.A.C.A. 23012 sections. The wing with flaps gave a very flat spin and neither this wing nor the one of 5:2 taper gave recovery.

Elevator-down spins (fig. 15) were very similar to elevator-neutral spins. Deflecting the elevators up (fig. 16) steepened the spin, making it difficult in some cases to test the model in the tunnel. Rapid recovery by reversal of both controls was obtained for all except the wing with flaps. With both controls neutral (fig. 17), spins were obtained for all except the rectangular wing with rectangular or faired tips. Wing 6 gave steeper spins, inward sideslip, and better recovery than wings 1 and 5.

For all control settings the rectangular wing with rectangular or faired tips gave the steepest spins and the most rapid recoveries. The wing of N.A.C.A. 6718 section, which had inward sideslip, also gave good recovery; but the remaining wings were unsatisfactory with tail C, except for the case of complete reversal of both controls from full with to full against the spin, a procedure that gave good recoveries for all except the wing with flaps. With the present loading, the wing with flaps gave a considerably flatter spin than with the basic loading and the remaining wings, with the exception of the rectangular wing with rectangular or faired tips, generally gave somewhat slower recoveries. The wing of N.A.C.A. 6718 section now had positive sideslip, and recovery was considerably improved as compared with that for the basic loading.

CONCLUSIONS

By comparative analysis of the data presented, the general effects of wing or tail arrangement and of control

position and the apparent relationships between spin characteristics may be determined for the loading condition of mass distributed along the fuselage.

Effect of wings:

1. Tip shape.- Rectangular and faired tips give the steepest spins and the most rapid recoveries. The Army tip gives consistently flatter spins and slower recoveries.

2. Section.- The N.A.C.A. 6718 wing gives a steeper spin and more rapid recovery than the other two sections. With tail C the N.A.C.A. 0009 wing gives slightly faster recoveries than the basic N.A.C.A. 23012 wing.

3. Flaps.- Flaps tend to retard recovery. With tail C they produce very flat spins.

4. Plan form.- The wing of 5:2 taper gives the poorest recoveries of all wings tested.

5. Army standard wing.- The Army standard wing is similar in behavior to the basic rectangular wing with Army tips.

Effects of tail arrangement:

For controls with the spin, tail B gives steeper spins than tail A and recovery is generally satisfactory for either tail. Tail C generally gives slower recoveries than either tail A or B.

Effects of control settings:

1. There is very little difference in recovery from spins with elevators down as compared with recovery from spins with elevators neutral.

2. Holding elevators up results in the steepest spins from which, by reversal of both controls, are obtained the most rapid recoveries.

Relationships between spin characteristics:

1. Steep spins are associated with high rate of descent, low $\Omega b/2V$, and rapid recovery.

2. There appears to be no direct relationship between the sideslip of the steady spin and the turns required for recovery.

Comparison with results for basic loading:

Comparison with the results for the basic loading condition shows:

1. For tails A and B there is little difference between results for the two loadings.

2. For tail C with the present loading the wing with flaps gives a much flatter spin and poorer recovery and the remaining wings generally give slower recoveries as compared with the basic loading condition. The wing of N.A.C.A. 6718 section gives very greatly improved recoveries.

Langley Memorial Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., November 8, 1937.

REFERENCES

1. Seidman, Oscar, and Neihouse, A. I.: Free-Spinning Wind-Tunnel Tests of a Low-Wing Monoplane with Systematic Changes in Wings and Tails. I. Basic Loading Condition. T.N. No. 608, N.A.C.A., 1937.

2. Zimmerman, C. H.: Preliminary Tests in the N.A.C.A. Free-Spinning Wind Tunnel. T.R. No. 557, N.A.C.A., 1936.

3. Shortal, Joseph A.: Effect of Tip Shape and Dihedral on Lateral-Stability Characteristics. T.R. No. 548, N.A.C.A., 1935.

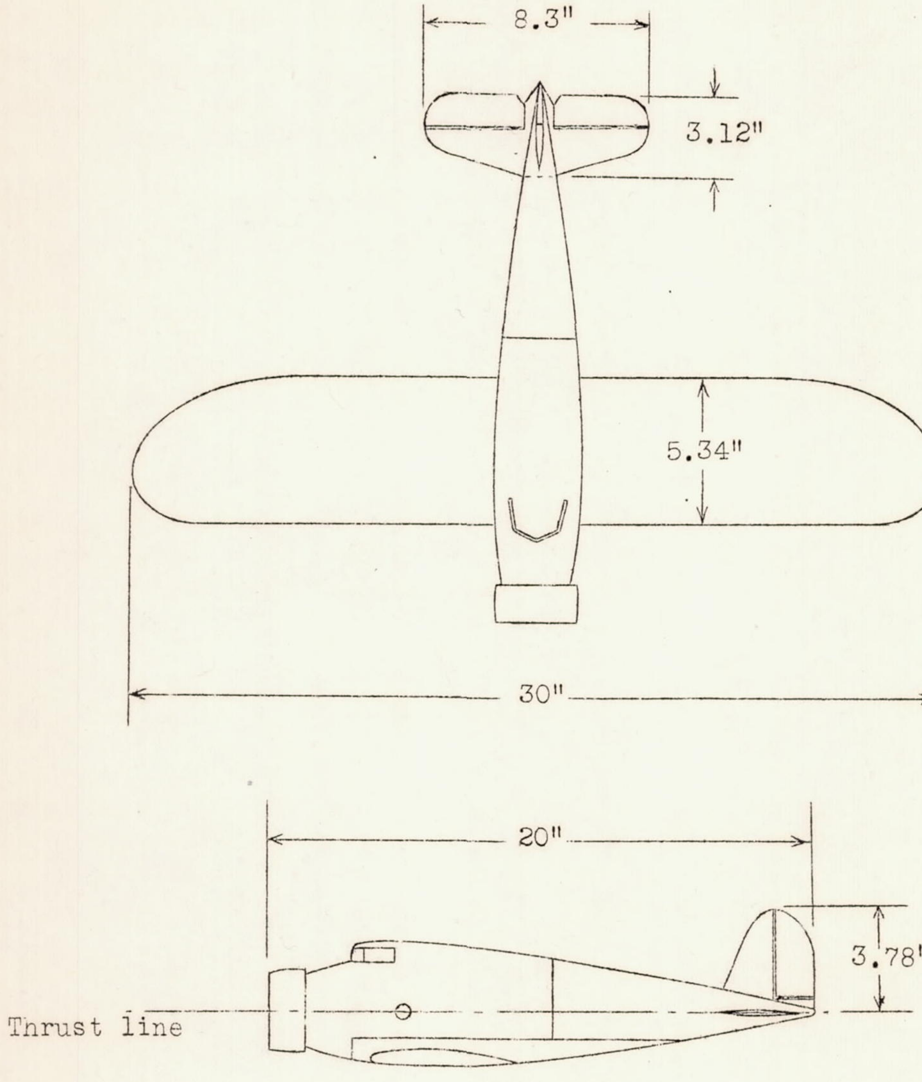


Figure 1.- Low-wing monoplane model with detachable tail and wing.

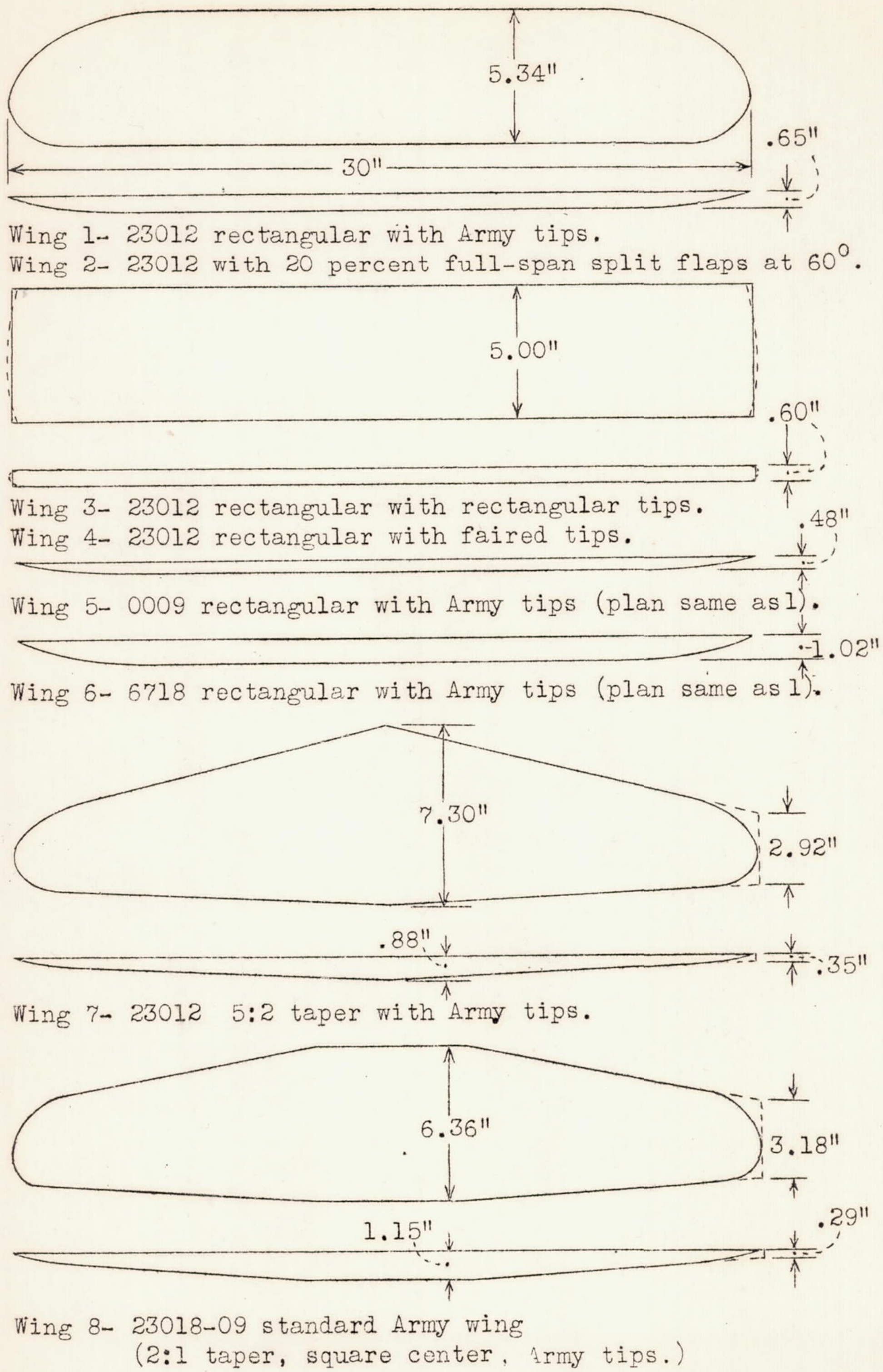
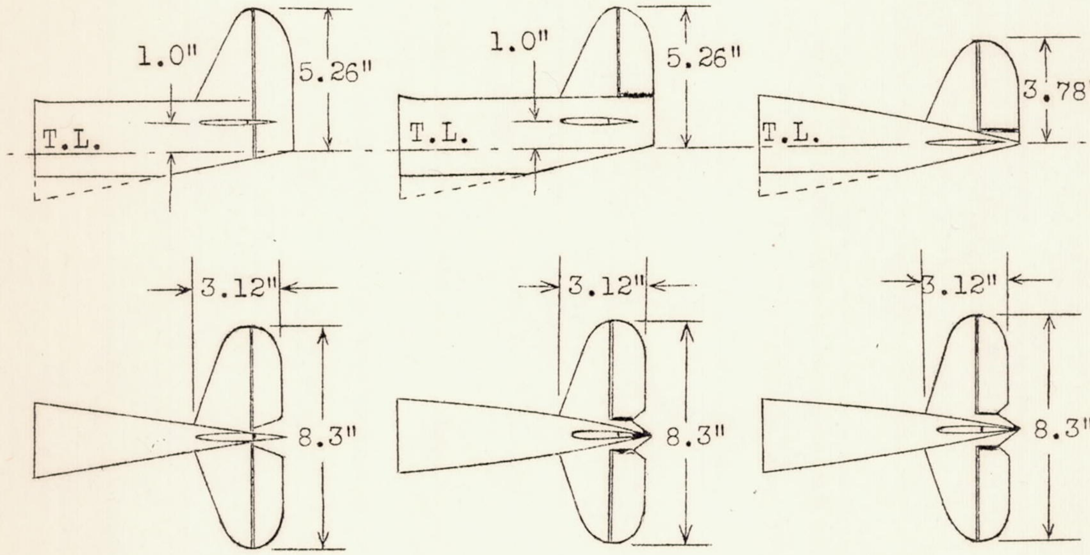


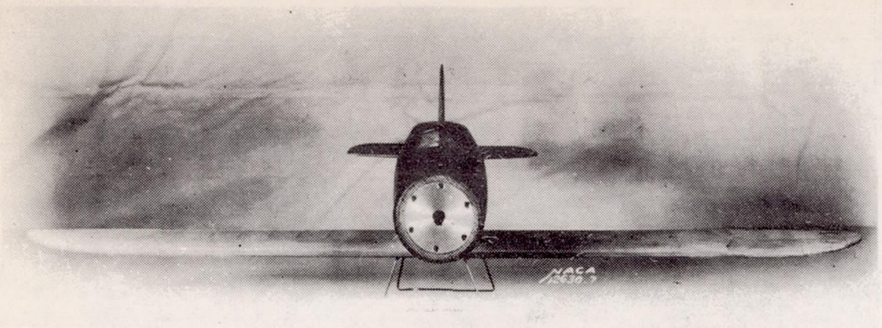
Figure 2.- Wings used on low-wing monoplane.
N.A.C.A. wing sections.

T.L. , thrust line

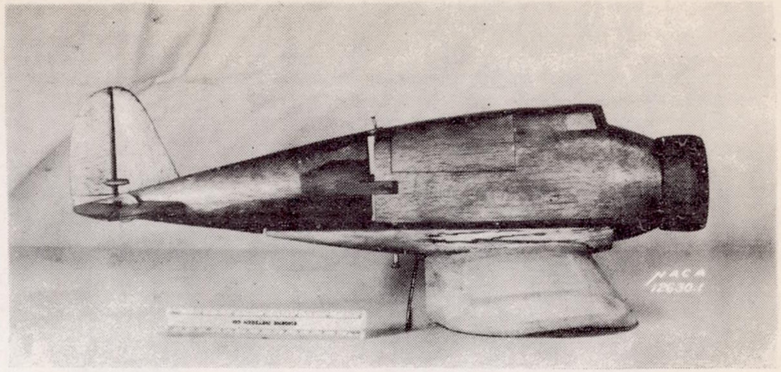


Tail A Tail B Tail C

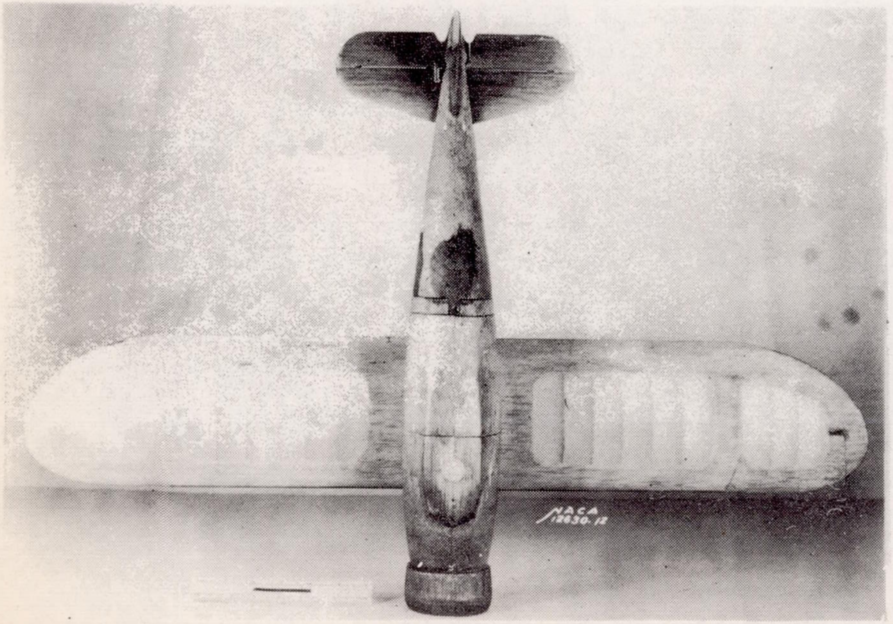
Figure 3.- Tails used on low-wing monoplane.



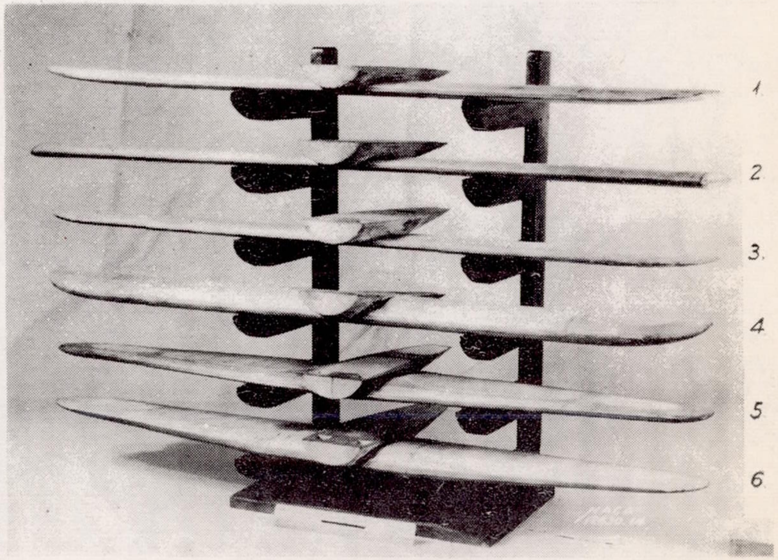
(a) Front view.



(c) Side view, showing detachable parts.



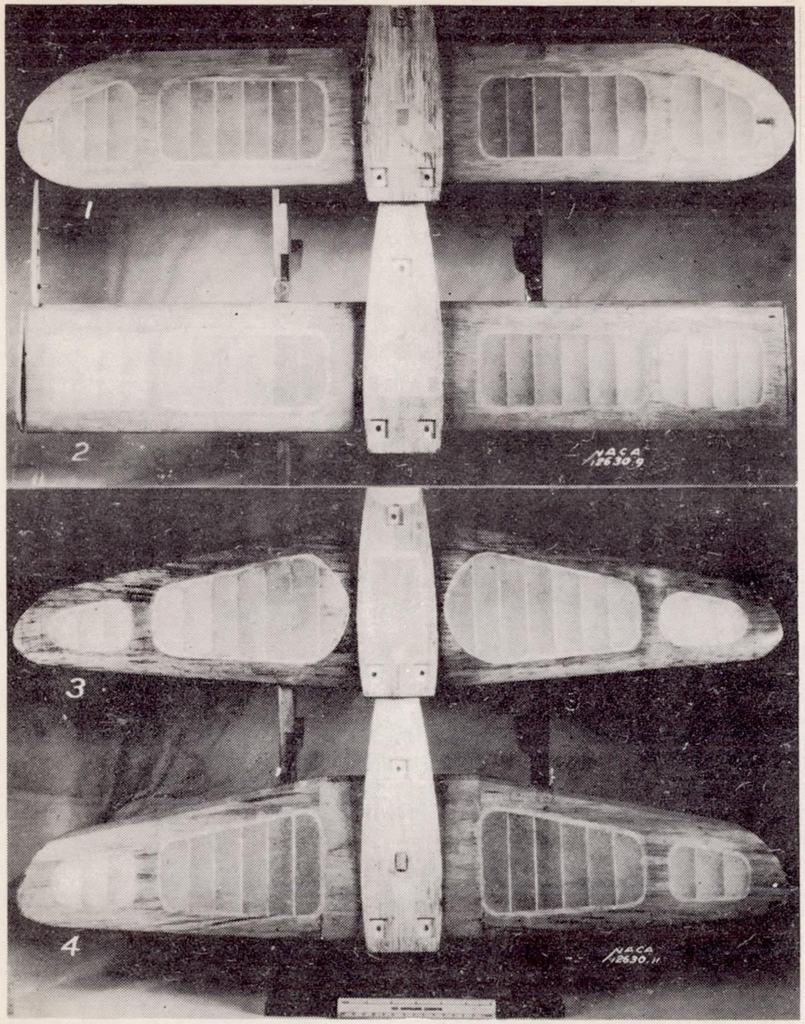
(b) Plan view.

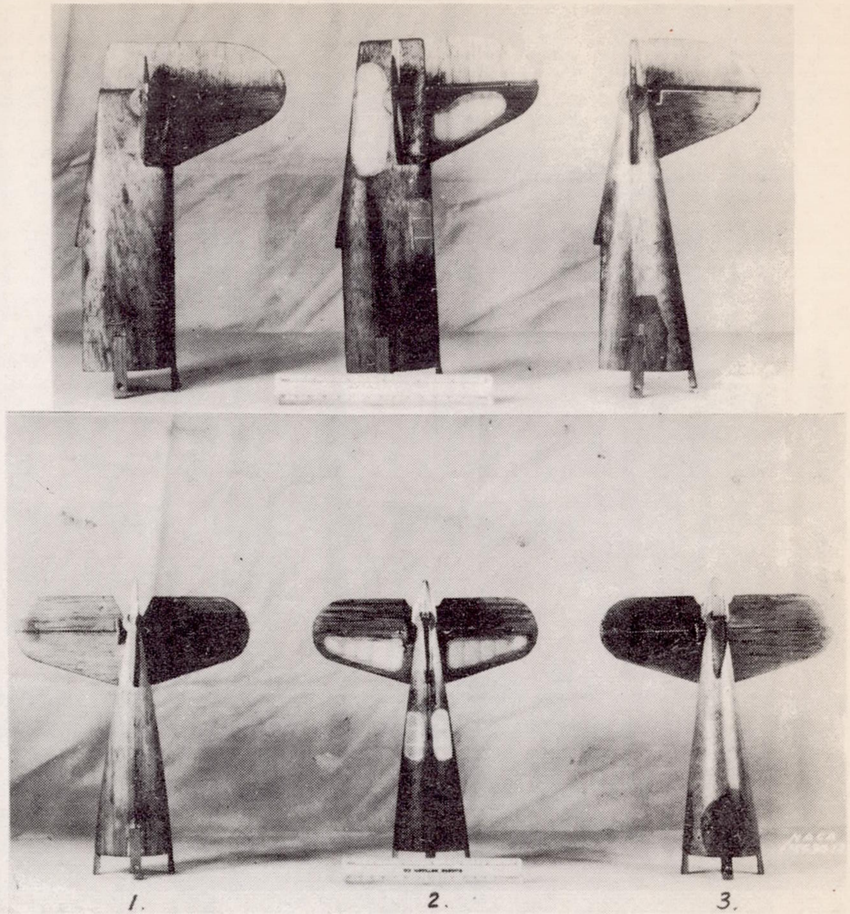


(1) Wings 1 and 2, (2) Wings 3 and 4, (3) Wing 5,
(4) Wing 6, (5) Wing 7 (6) Wing 8.

(d) Low-wing monoplane wings.

Figure 4. - Low-wing monoplane model.





(b) (1) Tail A, deep fuselage and long rudder.
(2) Tail B, deep fuselage and short rudder.
(3) Tail C, shallow fuselage and short rudder.

(a) (1) Rectangular wing with Army tips. (2) Rectangular wing with interchangeable rectangular and faired tips.
(3) 5:2 tapered wing with Army tips.
(4) 2:1 Army standard tapered wing with square center.

Figure 5.- Interchangeable wings and tails of low-wing monoplane model.

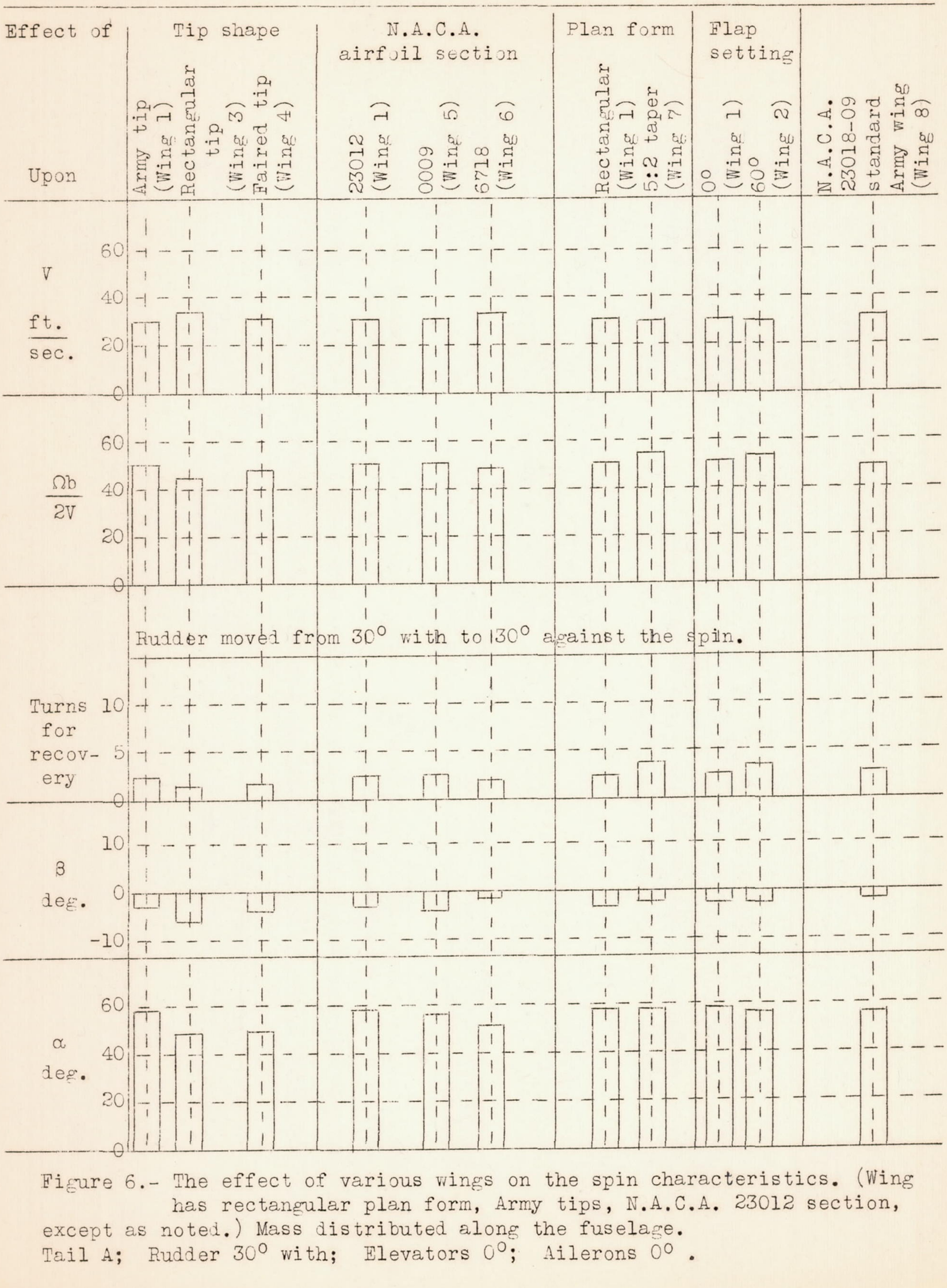


Figure 6.- The effect of various wings on the spin characteristics. (Wing has rectangular plan form, Army tips, N.A.C.A. 23012 section, except as noted.) Mass distributed along the fuselage. Tail A; Rudder 30° with; Elevators 0°; Ailerons 0° .

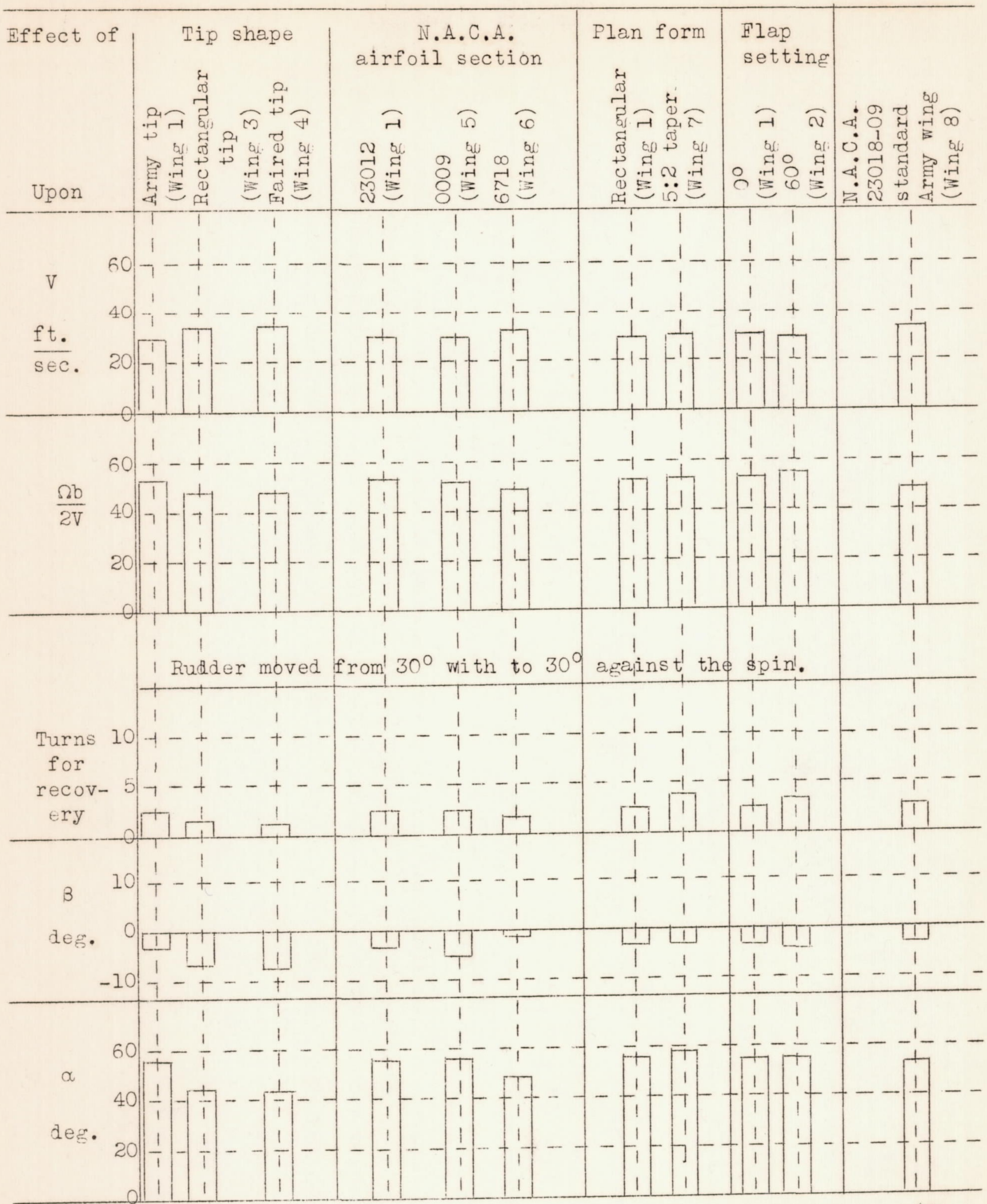


Figure 7.- The effect of various wings on the spin characteristics. (Wing has rectangular plan form, Army tips, N.A.C.A. 23012 section, except as noted.) Mass distributed along the fuselage. Tail A; Rudder 30° with; Elevators 20° down; Ailerons 0°.

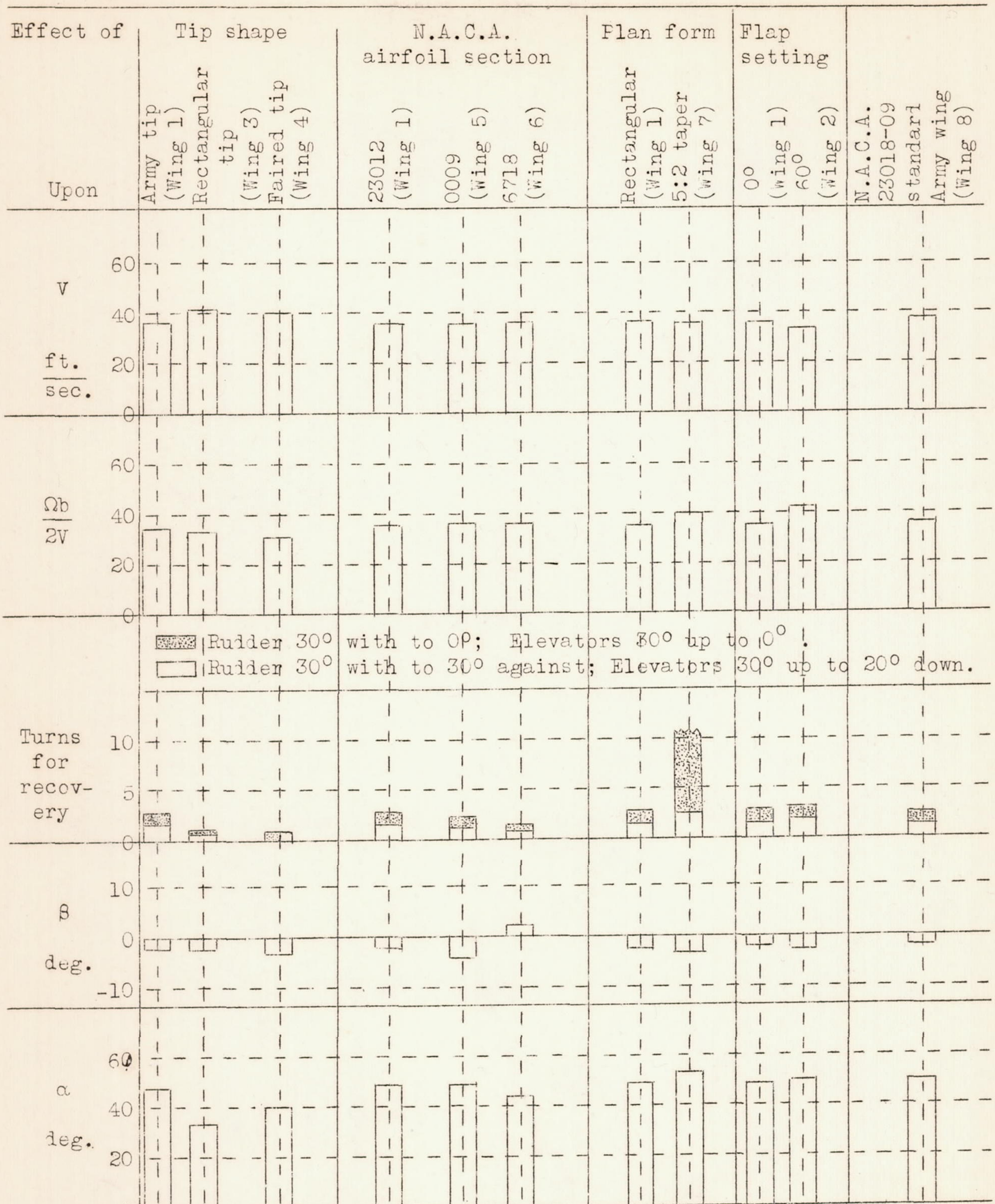


Figure 8.- The effect of various wings on the spin characteristics. (Wing has rectangular plan form, Army tips, N.A.C.A. 23012 section, except as noted.) Mass distributed along the fuselage. Tail A; Rudder 30° with; Elevators 30° up; Ailerons 0° .

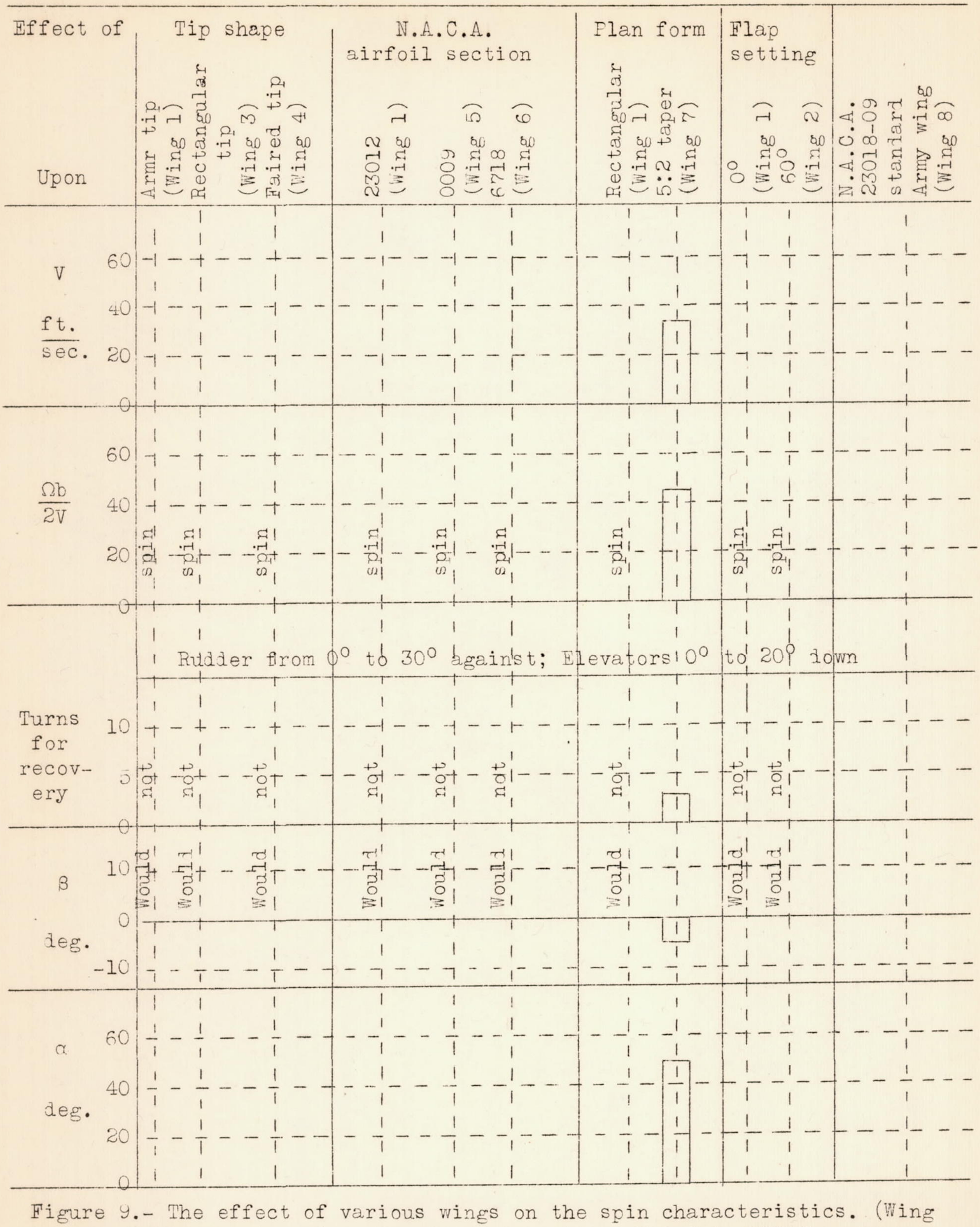


Figure 9.- The effect of various wings on the spin characteristics. (Wing has rectangular plan form, Army tips, N.A.C.A. 23012 section, except as noted.) Mass distributed along the fuselage.
Tail A; Rudder 0°; Elevators 0°; Ailerons 0° .

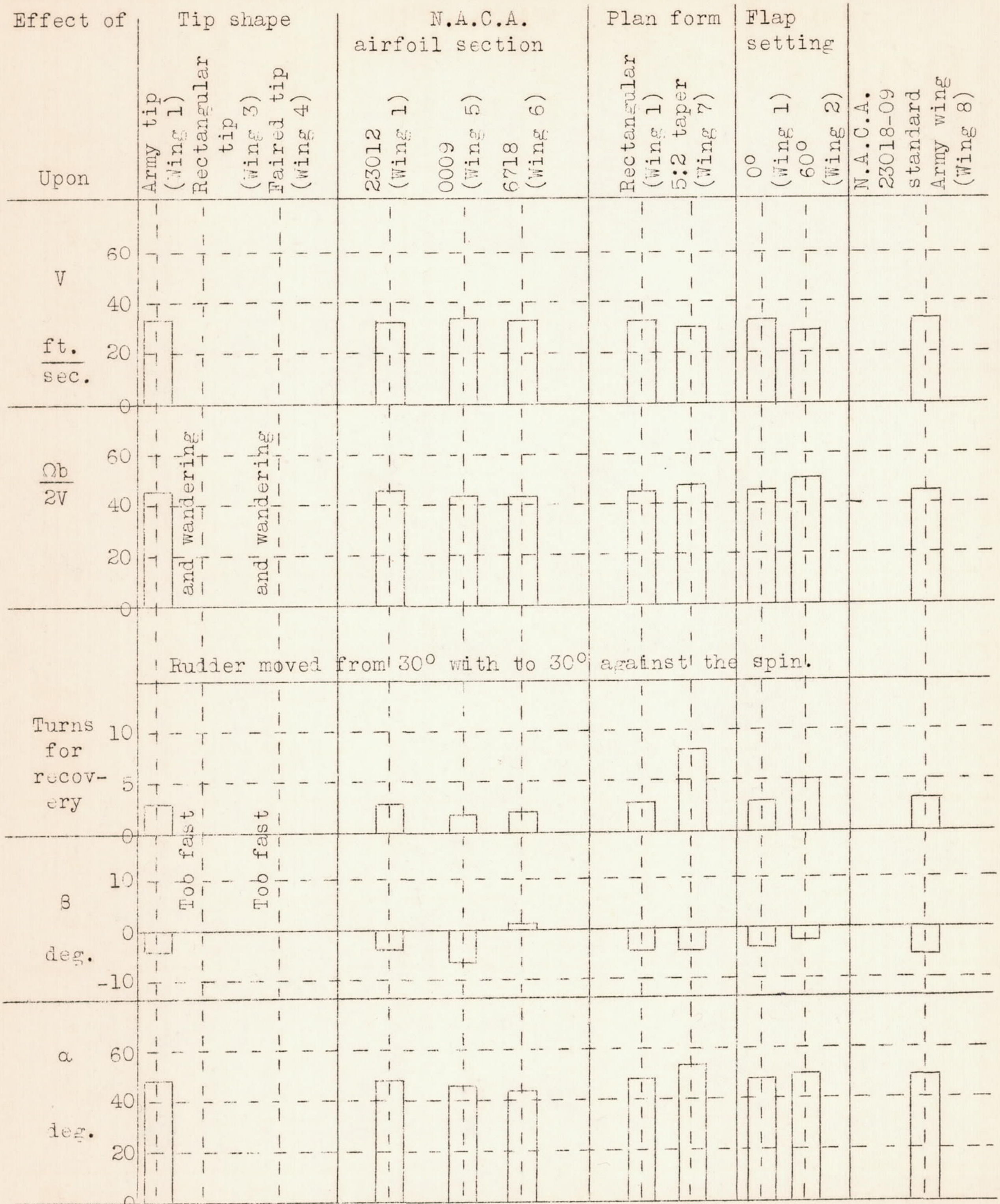


Figure 10.- The effect of various wings on the spin characteristics. (Wing has rectangular plan form, Army tips, N.A.C.A. 23012 section, except as noted.) Mass distributed along the fuselage. Tail B; Rudder 30° with; Elevators 0°; Ailerons 0° .

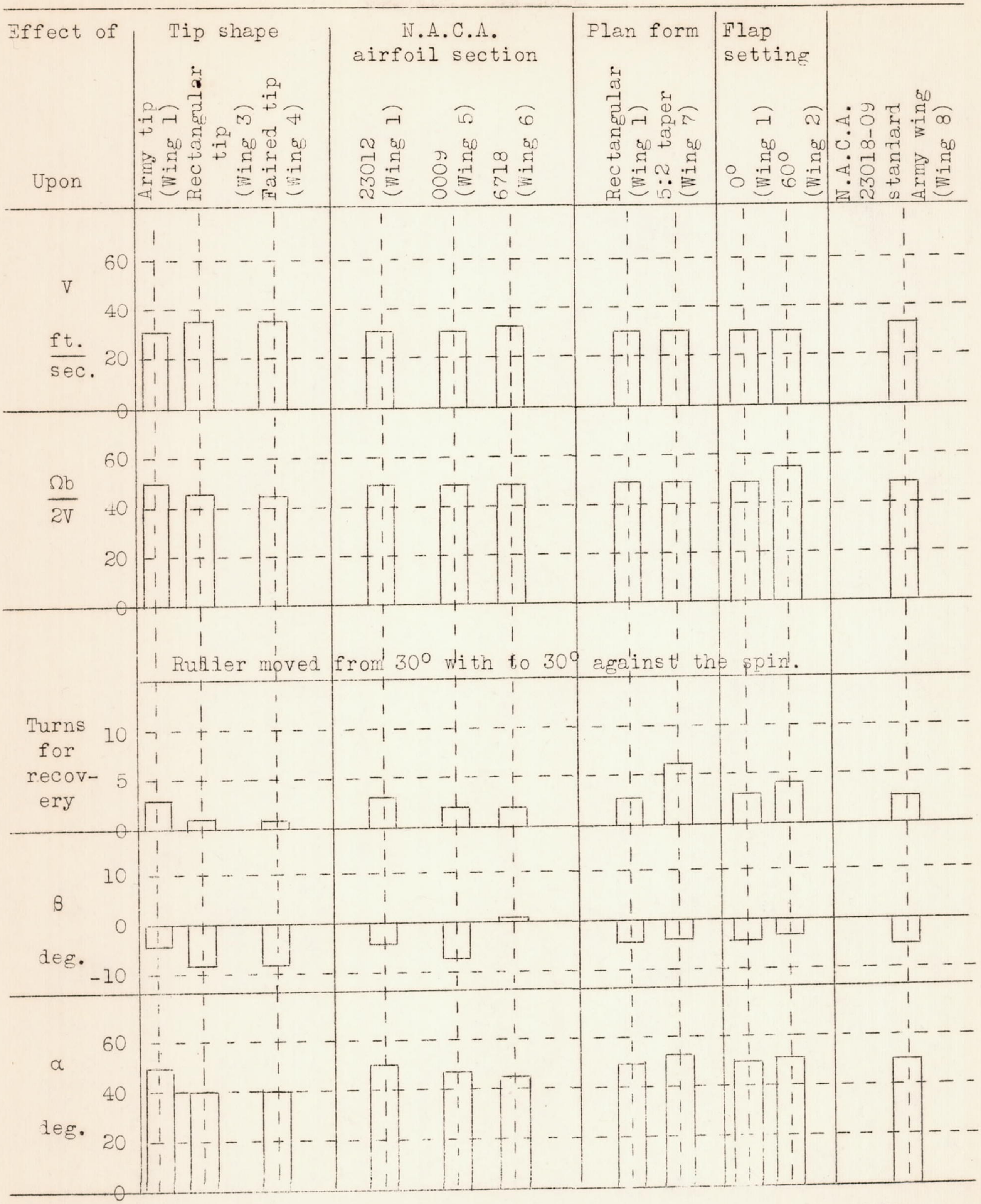


Figure 11.- The effect of various wings on the spin characteristics. (Wing has rectangular plan form, Army tips, N.A.C.A. 23012 section, except as noted.) Mass distributed along the fuselage. Tail B; Rudder 30° with; Elevators 20° down; Ailerons 0°.

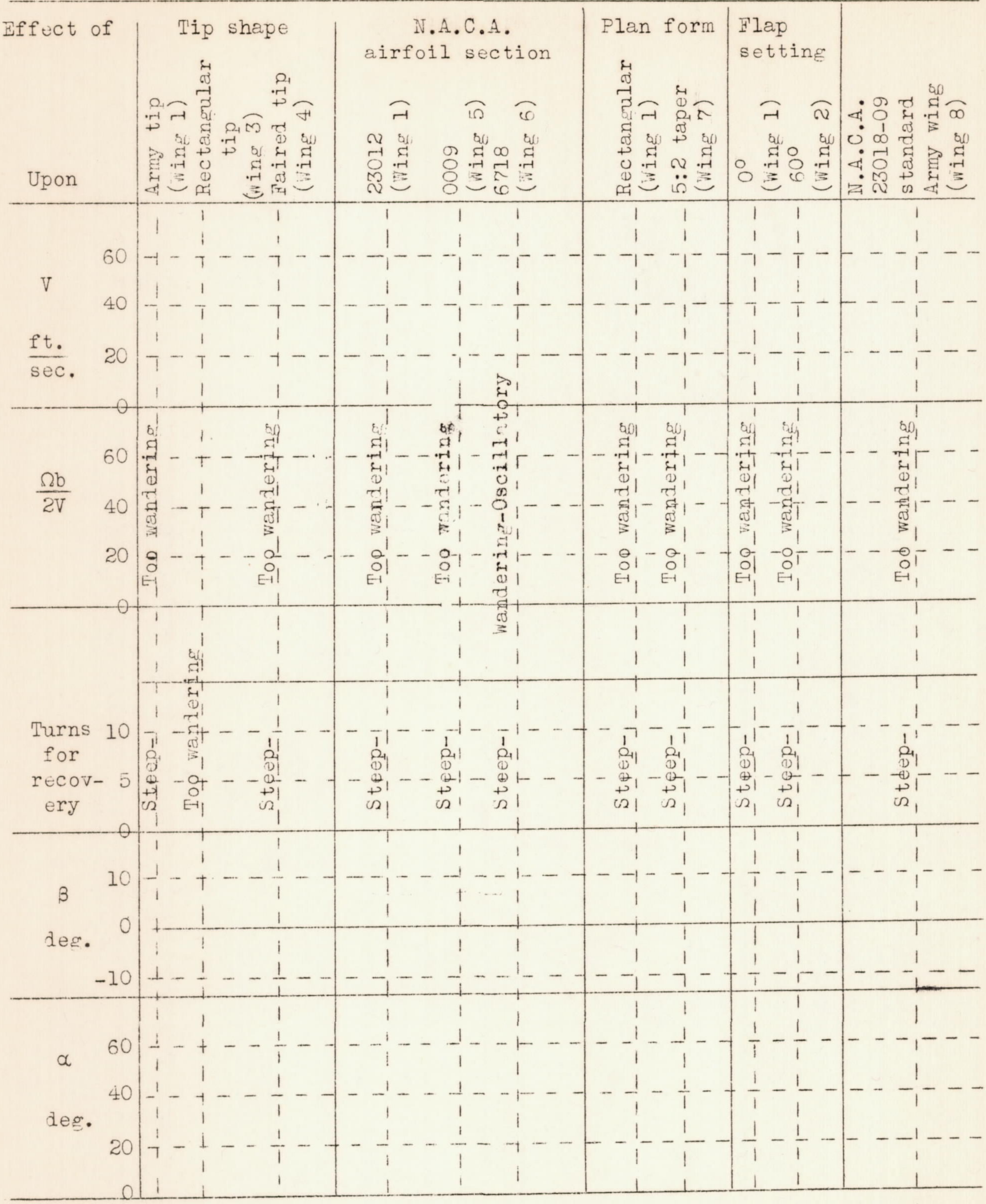


Figure 12.- The effect of various wings on the spin characteristics. (Wing has rectangular plan form, Army tips, N.A.C.A. 23012 section, except as noted.) Mass distributed along the fuselage. Tail B; Rudder 30° with; Elevators 30° up; Ailerons 0° .

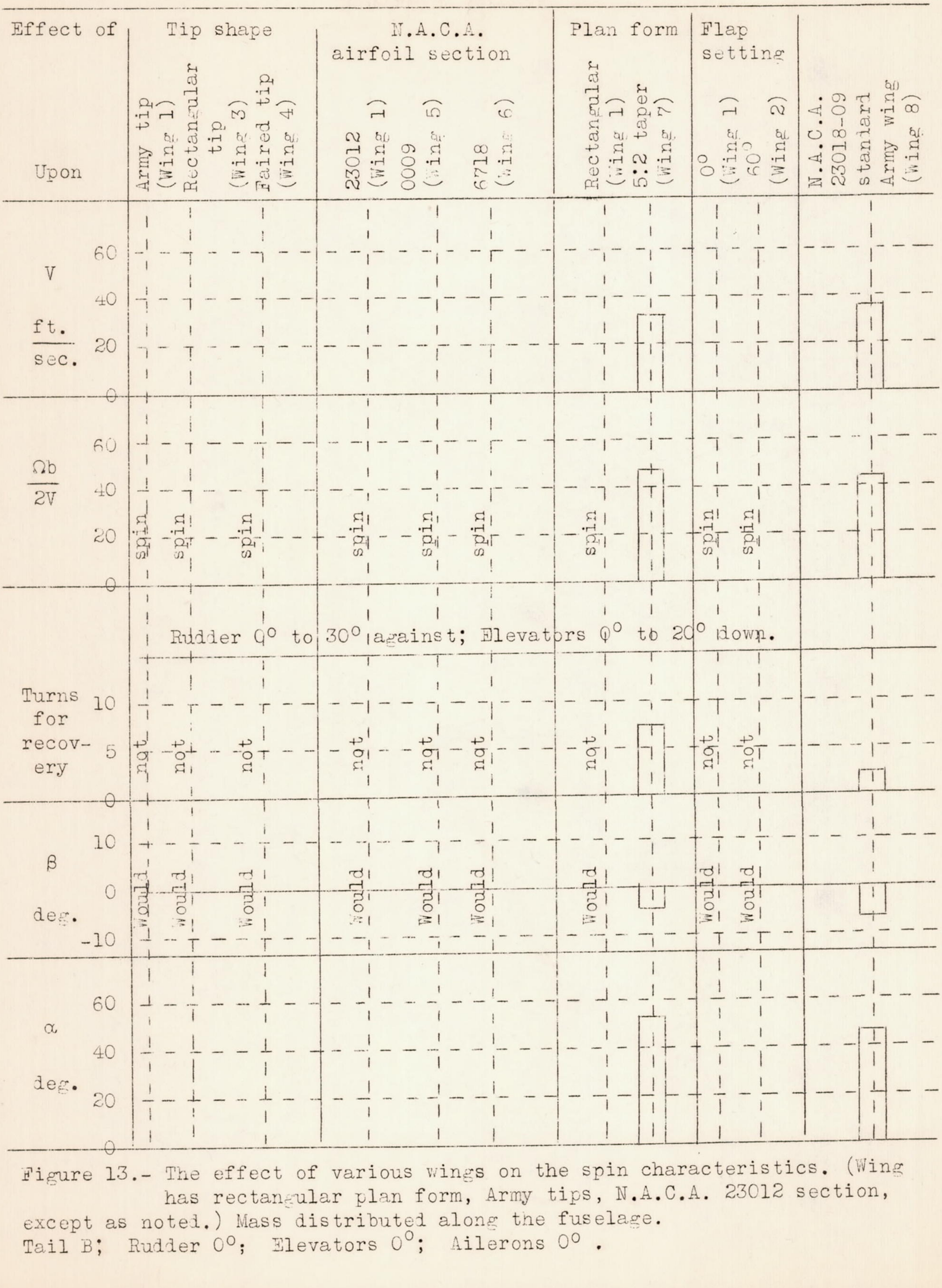


Figure 13.- The effect of various wings on the spin characteristics. (Wing has rectangular plan form, Army tips, N.A.C.A. 23012 section, except as noted.) Mass distributed along the fuselage.
Tail B; Rudder 0°; Elevators 0°; Ailerons 0° .

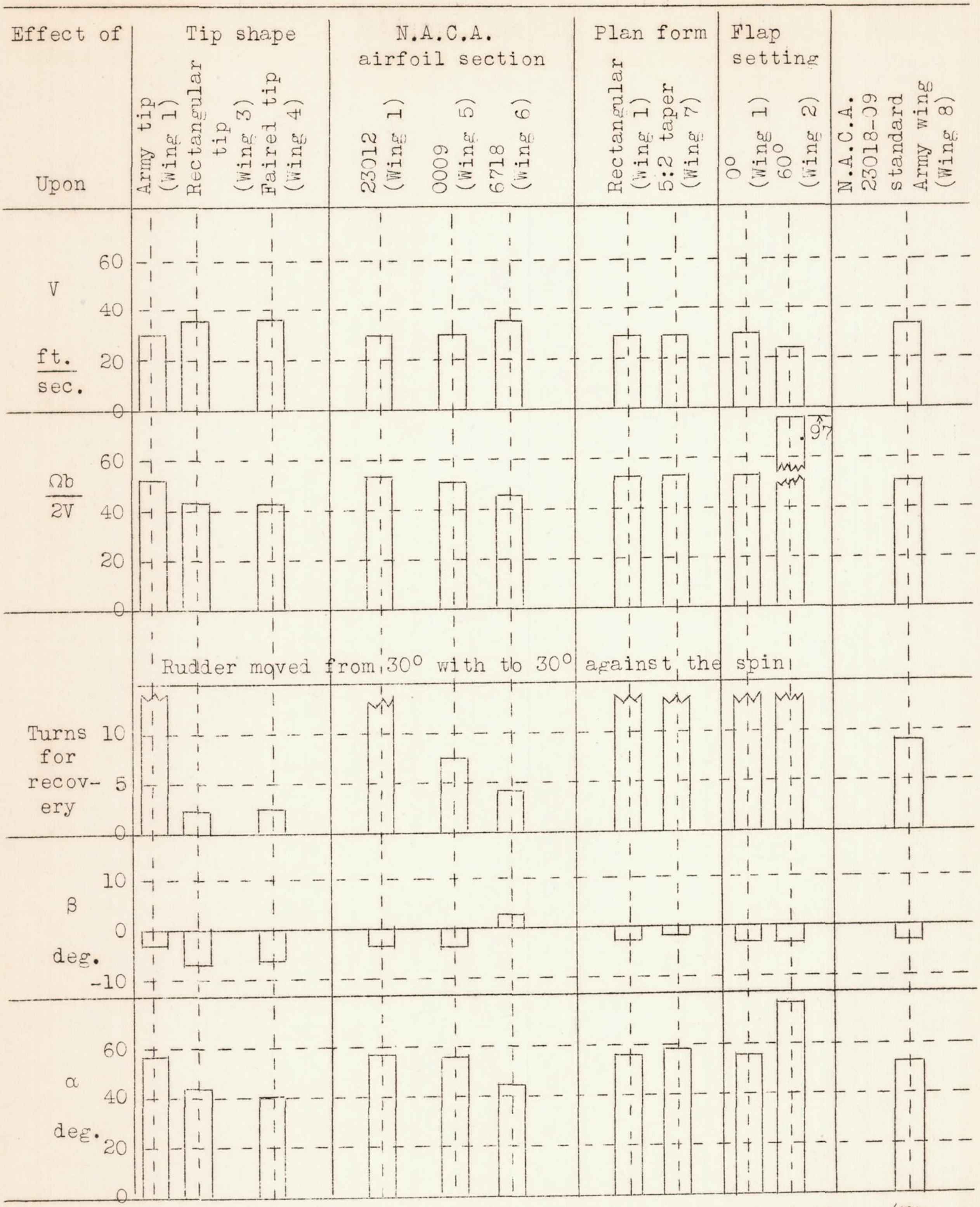


Figure 14.- The effect of various wings on the spin characteristics. (Wing has rectangular plan form, Army tips, N.A.C.A. 23012 section, except as noted.) Mass distributed along the fuselage. Tail C; Rudder 30° with; Elevators 0°; Ailerons 0° .

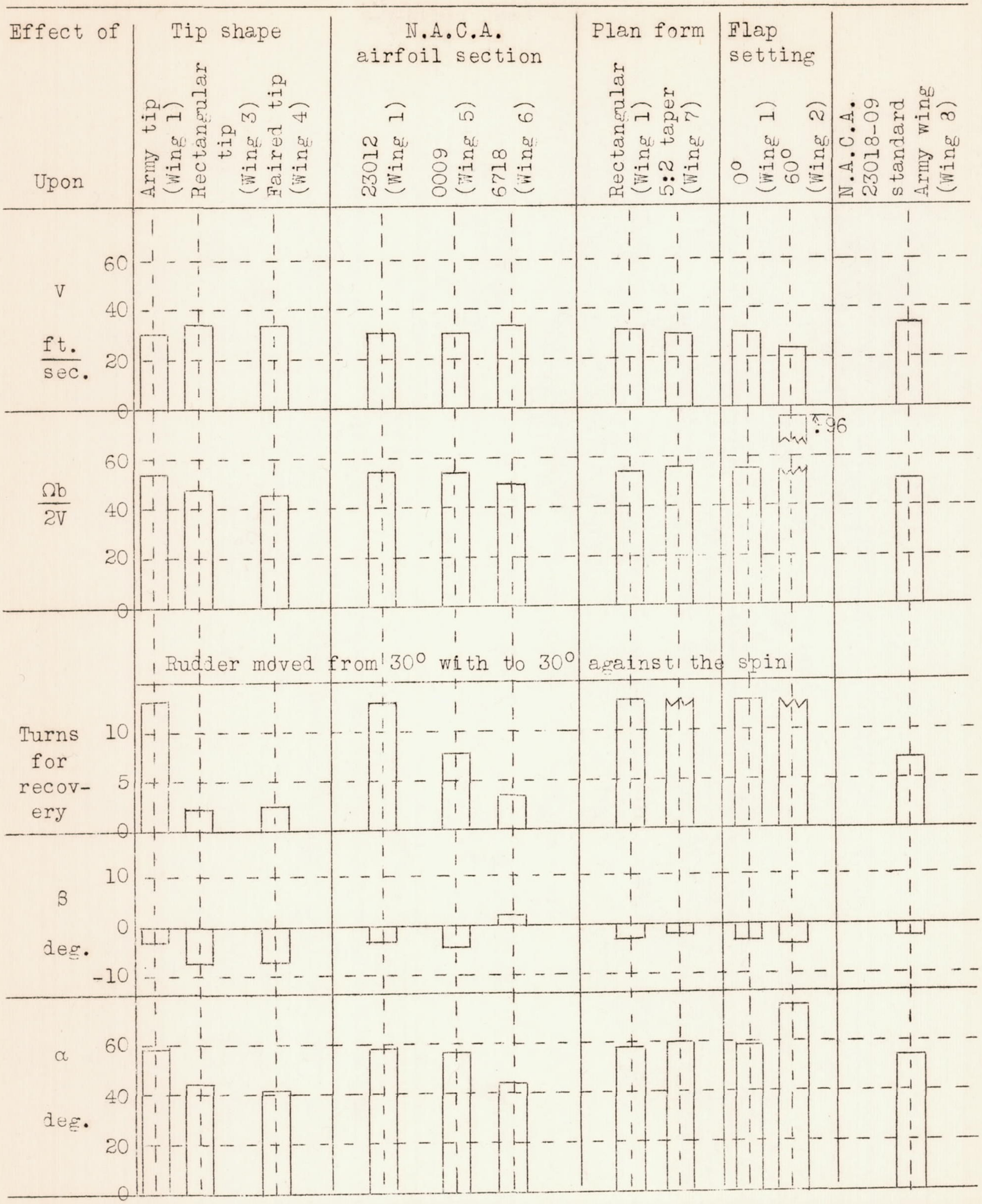


Figure 15.- The effect of various wings on the spin characteristics. (Wing has rectangular plan form, Army tips, N.A.C.A. 23012 section, except as noted.) Mass distributed along the fuselage.
Tail C; Rudder 30° with; Elevators 20° down; Ailerons 0°.

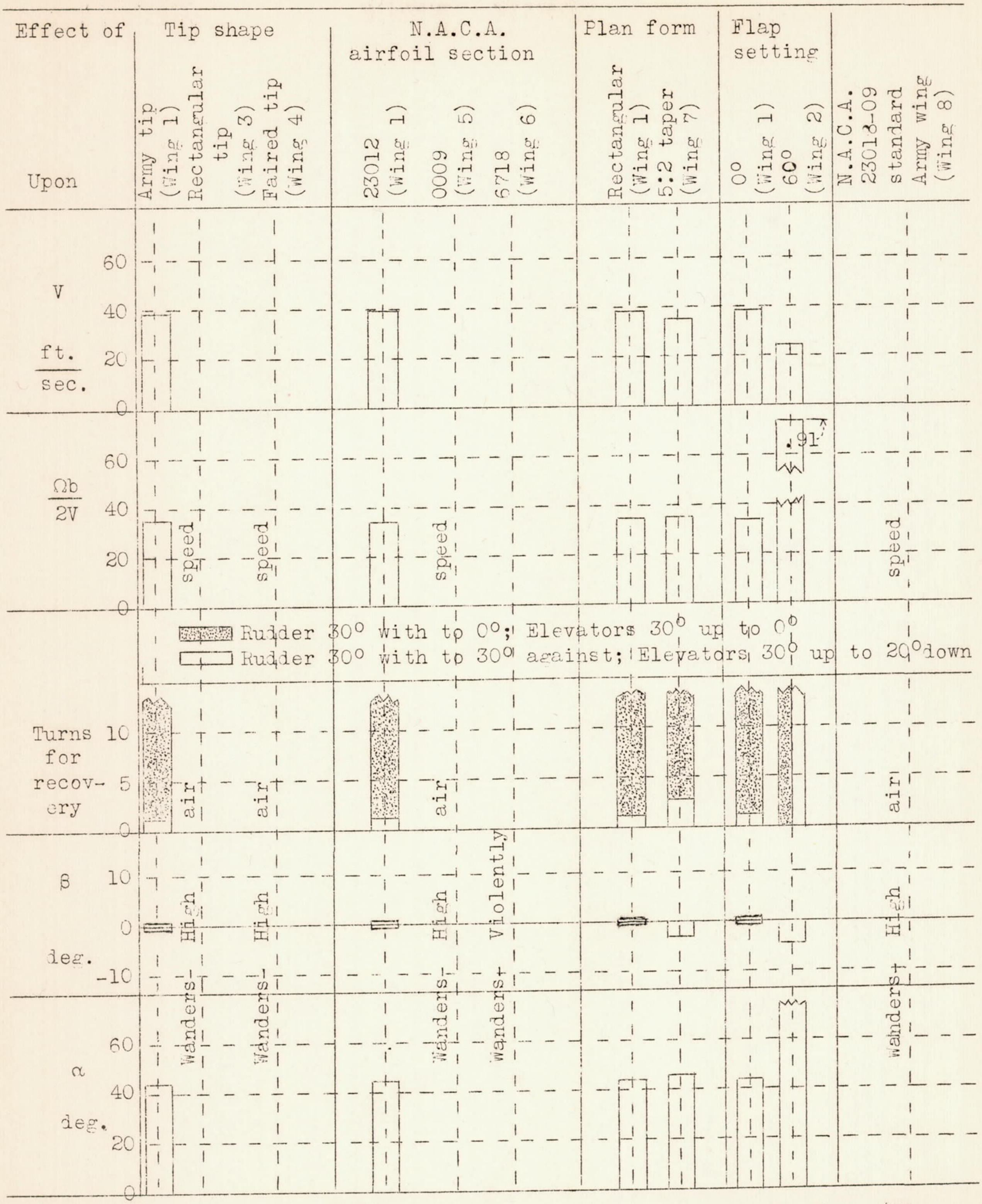


Figure 16.- The effect of various wings on the spin characteristics. (Wing has rectangular plan form, Army tips, N.A.C.A. 23012 section, except as noted.) Mass distributed along the fuselage. Tail C; Rudder 30° with; Elevators 30° up; Ailerons 0° .

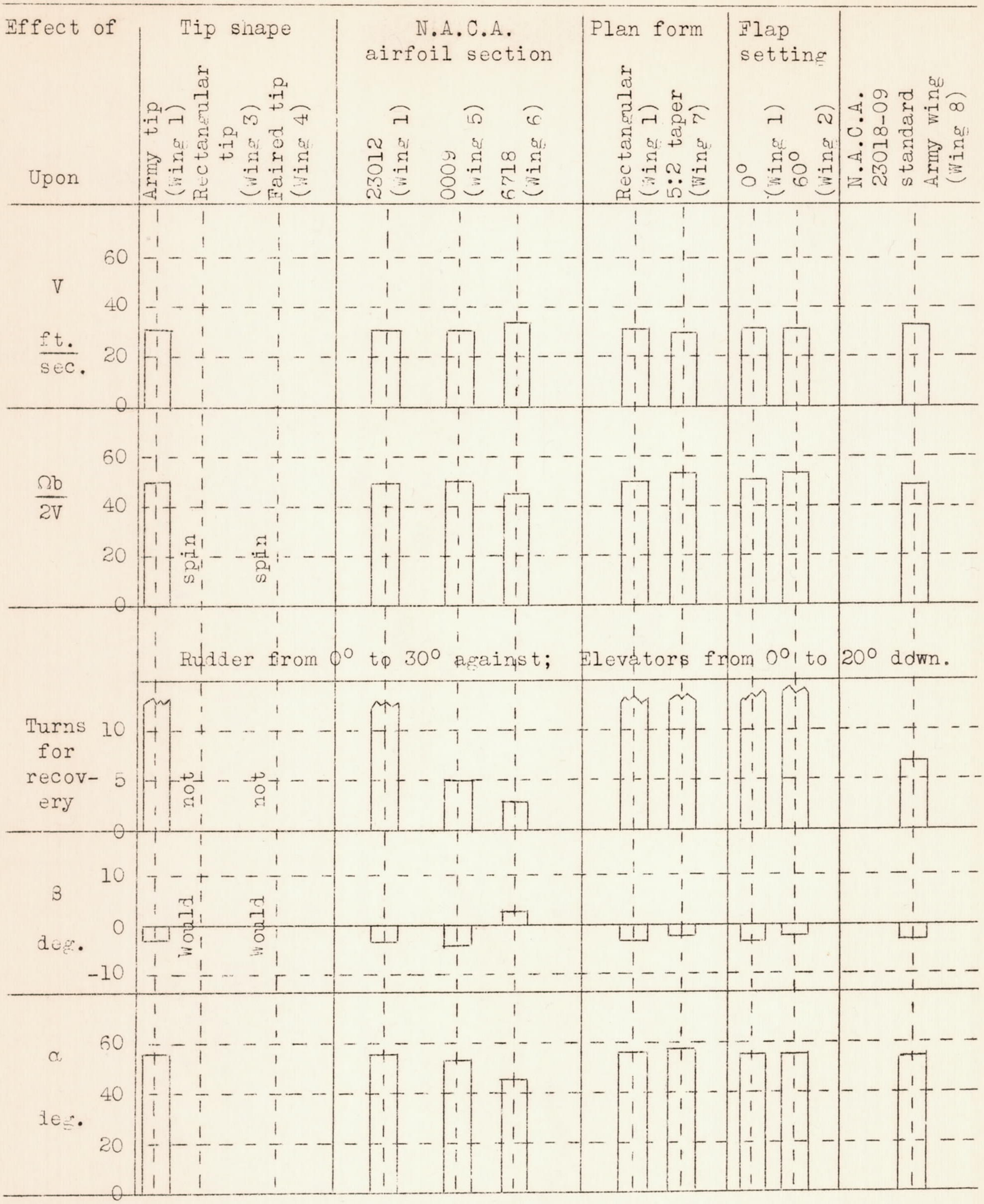


Figure 17.- The effect of various wings on the spin characteristics. (Wing has rectangular plan form, Army tips, N.A.C.A. 23012 section, except as noted.) Mass distributed along the fuselage. Tail C; Rudder 0°; Elevators 0; Ailerons 0°.